Control of *Ixodes scapularis* (Acari: Ixodidae) with topical self-application of permethrin by white-tailed deer inhabiting NASA, Beltsville, Maryland

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ABSTRACT: We report the first successful area-wide reduction of *Ixodes scapularis* by using minimal amounts of permethrin self-applied by free-ranging white-tailed deer in as little as 3 y of nearly continuous treatment. The study to control all active stages of *I. scapularis* Say was initiated in April 1995, at the Goddard Space Flight Center, National Aeronautics and Space Administration (NASA), Beltsville, Maryland (treated location), and the Patuxent Wildlife Research Center, Laurel, Maryland (non-treated location). The locations had similar flora and fauna, and pre-treatment sampling (April to October 1995) of deer, plots, and mice for *I. scapularis* indicated nearly similar tick populations at both locations. After pre-treatment sampling, 4 deer '4-poster' stations were placed at NASA, while the control area received none. Ten percent permethrin, supplied to 4 roller covers on each station, was passively transferred to the head, neck, and ears of free-ranging deer feeding at the stations. This treatment resulted in elimination of adult *I. scapularis* on sampled deer (100% control) by the 2nd y of treatment and reductions of immature tick stages on mice. During the 3rd y of treatment, adult, nymphal, and larval questing ticks were reduced by 91-100% from sampled plots, and nymphal and larval ticks were reduced by 70-95% on sampled mice. ***Journal of Vector Ecology* 28(1): 117-134. 2003.**

Keyword Index: Tick control, deer ticks, deer ectoparasites, '4 Poster', Lyme disease.

INTRODUCTION

In the northeastern and north-central U.S., tick-borne pathogens that cause Lyme disease, human granulocytic ehrlichiosis, and babesiosis are transmitted to humans by the black-legged tick, *Ixodes scapularis* Say. The incidence of these diseases has increased almost every year (Centers for Disease Control 2001), presumably caused by frequent interactions among humans, deer, and infected ticks in the same areas during the same time periods, usually spring through autumn.

Methods to control ticks include area-wide dispersal of insecticides (Schluze et al. 1984, Solberg et al. 1992, Battaly and Fish 1993, and Stafford 1997), which is effective though poses adverse effects on non-target organisms. Habitat modification, such as burning of underbrush, may initially control ticks but is rarely used because it is environmentally destructive. Elimination of deer (Wilson et al. 1988, Stafford 1993, Deblinger et al. 1993) is not well accepted by the public. Close mowing also helps control ticks, but many people bitten in endemic areas are bitten by *I. scapularis* from their own close-cut lawns (Falco and Fish 1988). New approaches to control ticks that are environmentally friendly, acceptable to local communities, more efficacious, and less expensive are needed.

One new approach is the self-application of small amounts of acaricide to free-ranging deer using a self-application system. Several different prototypes of the system were developed, briefly tested, and shown to be effective for decreasing ticks on domesticated goats (Sonenshine 1991), pastured deer (Duncan and Monks 1992), and 11 free-ranging white-tailed deer (Sonenshine et al. 1996). The '4-poster' deer station (Figure 1),

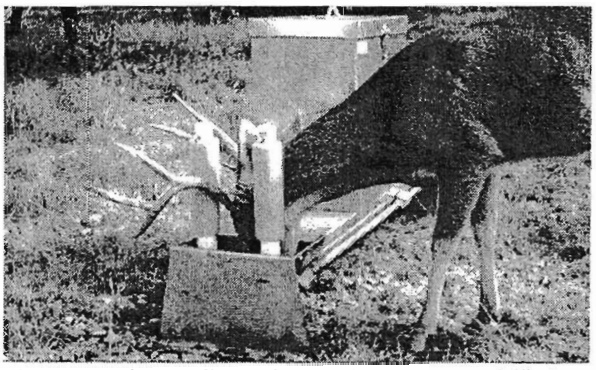

Figure 1. A deer feeding and passively applying acaricide from '4-Poster' Feeding and Application Station.

patented by Pound et al. (1994), was tested in preliminary studies using 1% permethrin self-applied by captive, penned deer, targeting *Amblyomma americanum* in Texas (TX) during 1994 (J.M. Pound and J.A. Miller, unpublished data). A 70% decrease in adult ticks on the treated deer was reported during the 2-mo test period.

The objectives of the present study were to: (1) determine if '4-Poster' deer stations, baited with corn and supplied with the insecticide permethrin, would attract and self-treat the majority of free-ranging deer with small amounts of permethrin (<30 gm Active Ingredient (AI)/deer/yr); (2) evaluate treatment efficacy as measured by an area-wide reduction (≥90%) of all active stages of *I. scapularis* both on and off deer, over a 3-y treatment period.

MATERIALS AND METHODS

Locations

This research was conducted in Prince George's County, Maryland. Two locations were selected for the study: Goddard Space Flight Center, National Air Space Administration (NASA), Main campus, Greenbelt, MD, and Patuxent Wildlife Research Center, Central Tract, Laurel, MD. These areas were selected because they had similar climate, flora, fauna, and topography. It also was reasonable to assume that tick species and populations, densities of deer and mice, and tick loads (number of ticks parasitizing hosts) would be similar. Both areas were either all (NASA) or mostly (Patuxent) enclosed by fencing, separated by several well-traveled roads, and 2.5 km apart, so it was unlikely that deer would move from one study site to another.

NASA was designated as the treated area because it was more secure, being entirely enclosed by a 2.6 m high security fence topped with 3 strands of double-angled barbed wire, even though the pre-selection of the treatment location had a 50-50 chance of introducing a source of bias. Patuxent was designated as the non-treated control area. It was enclosed on 3 sides by a 1.8-2.1 m high chain-link fence and on the 4th side by the Patuxent River. The locations differed in area, NASA being approximately 2.55 km^2 total with approximately 1.21 km^2 of usable deer habitat, while Patuxent totaled 10.1 km^2, with 5.3 km^2 of usable deer habitat. Pre-treatment sampling for all active stages of ticks was conducted in 1995, while post-treatment sampling was conducted from 1996-1998.

Research was conducted in compliance with the Animal Welfare Act and other Federal and Maryland state statutes and regulations relating to animals and experiments involving animals and adhered to principles as stated in the "*Guide for the Care and Use of Laboratory Animals*," NRC Publications, 1996 edition. All procedures were reviewed and approved by the Animal Care and Use Committee (University of Maryland, College Park, MD), Protocol Number R-95-59.

Sampling deer for ticks

Ticks parasitizing deer at NASA were compared to those at Patuxent during pre- and post-treatment for a total of 4 y. Six to 12 deer were sampled at each location August to December from 1995 through 1998 for autumn sampling, and March to June from 1996 through 1998 for spring sampling. Only autumn data for each year were shown because only these data were collected for the pre-treatment period. In addition, only infestation of adult ticks was reported because the majority of deer were sampled when immature ticks were not active.

Deer were immobilized by an intramuscular injection of 6 mg/kg xylazine hydrochloride administered using a 1 or 2 cc rifle-fired dart (Pneu-Dart, Williamsport, PA). Immobilized deer were blindfolded to help prevent struggling. A color-coded numbered ear tag (Allflex™ USA, DFW Airport, TX) was attached to the right ear of each sampled deer at NASA and to both ears at Patuxent. The sex and age, based on tooth examination (Giles 1978) of the deer, were estimated and recorded. Only the head, ears, neck, chest, and front axillary regions of deer were checked for the presence of ticks by close visual observation and running fingers carefully through the coat in a systematic manner. These areas of the deer contain the majority of all ticks (Schmidtmann et al. 1998), and since we were limited somewhat in time by the deer's reaction to the anesthesia, we checked the most abundant areas. All ticks were identified to species, stage, and sex, using a hand lens (10 x) and samples of adult *I. scapularis* were returned to the laboratory for microscopic confirmation of identification using the

guide by Keirans and Litwak (1989). Deer were generally revived within 20 min with a 3-5 cc intravenous injection of 0.2 mg/kg of yohimbine hydrochloride. Deer usually regained full motor control within 2-5 min and quickly left the capture area.

Sampling plots for ticks

Fifteen sampling grids, 250 m^2, were selected at random in wooded or ecotone areas from both sites. Initially 2- 10 x 10 m^2 (100 m^2) plots were randomly selected per grid. Each corner of the plot was marked, and the entire plot was dragged to determine the numbers of questing ticks per plot. A 1 m^2 drag (Sonenshine 1991) was placed in a corner of the plot and was pulled slowly through/over the underbrush to an adjacent corner (row 1). The drag was carefully moved over 1 m and pulled adjacent (row 2) to the first drag path. Ticks on the drag were counted after each 2 rows, identified with a hand lens (10x), and a sample was taken back to the laboratory for microscopic confirmation of identification. The remaining ticks were removed from the drag and returned to the center of the rows just dragged. Where larvae were too numerous to count, the whole plot was dragged, larvae on one quarter of the drag were counted and the number multiplied by 4 for an estimated count. After sampling, if numerous larvae were still on the drag, the drag was inverted over a shrub or small tree limb and left hanging overnight. Another identical drag was used for the next plot. Ticks were processed in the laboratory as discussed above. A minimum of 2 plots per location was dragged weekly unless prevented by rain or unavoidable circumstances from April through July 15 (Figure 2), when all tick stages were active. No autumn drag sampling was conducted for adult ticks.

Sampling mice for ticks

Sherman live-capture box traps (7.6 by 8.9 by 22.9 cm; Sherman Traps, Inc., Tallahassee, Florida) were set weekly from June 1 to August 15th, immediately after dragging the test plots (Figure 2). During 1995, 4 traps were set at each plot 10 x 10 m plot. During 1996-1998, 4 to 8 traps were set at or near each plot (within 15 m from the center of the plot) to try to improve trapping success. The same numbers of traps were set at NASA

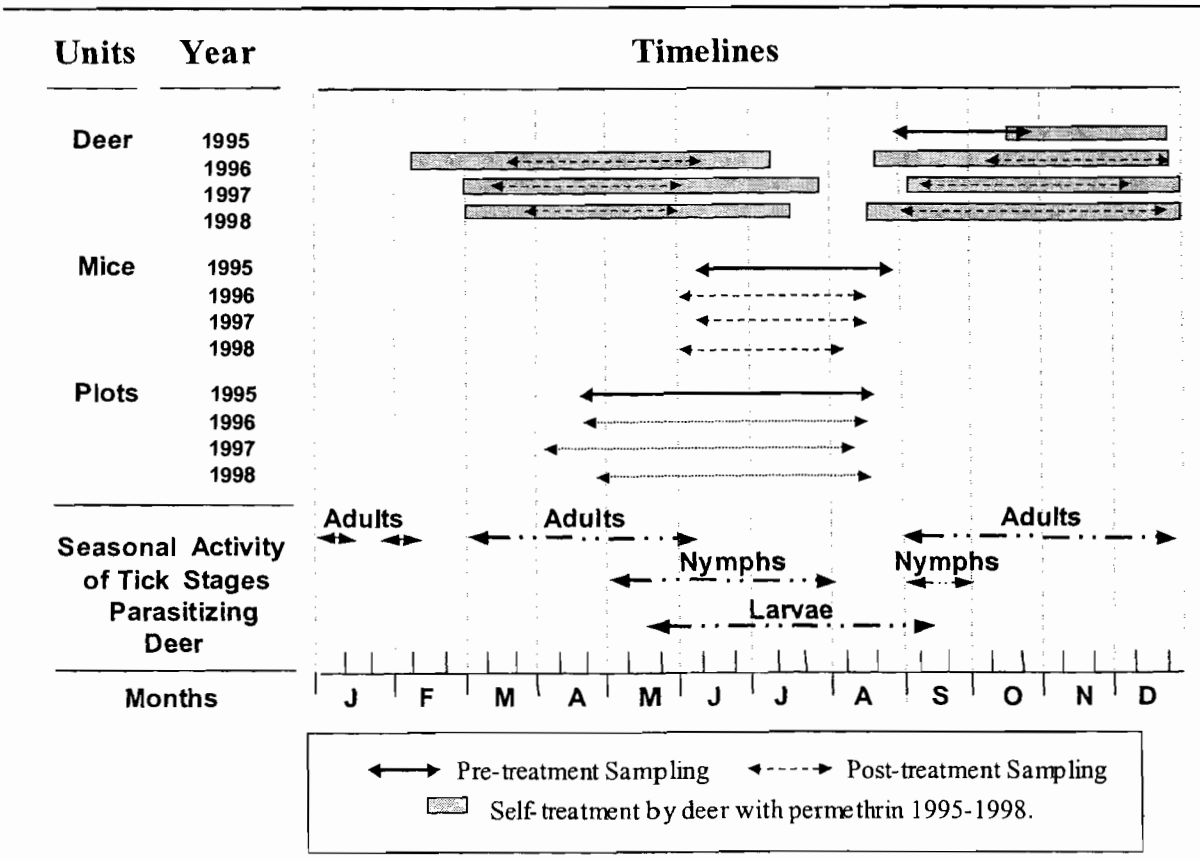

Figure 2. Sampling, permethrin treatment, and seasonality time lines.

and Patuxent during the same week except when occasional rain prevented trapping. The traps were baited with peanut butter and set between 1800 to 2000 (EST) hours and checked the next morning between 0600 to 0800 hours. Each trapped mouse (15-20 gms) was anesthetized at the time of capture with a mixture of ketamine (10 mg/ml): Rompum (100 mg/ml): sterile water (2.5:0.5:8.0 ml) to an effective light level of anesthesia. Each mouse was identified to species using the Audubon Society Field Guide to North American Mammals (Whitaker 1980). Larval and nymphal ticks were counted on the mouse and a sample of ticks taken back to the laboratory for confirmation of identity. Each mouse was sexed, the data recorded, and the mouse then released at the point of capture once activity returned.

'4-Poster' deer stations

We used 22.9 cm long paint roller covers on the roller holders of each station (Figure 1). During the first two years, foam-type paint roller (Slick Foam Roller Cover, Model/style 07040, 2.1 cm foam; Shur-line, Inc., Lancaster, NY) were used. The last two years the covers were switched to sturdier fiber-type paint covers (Pylan Synthetic Lambskin, extra rough surface, Synthetic Lambskin, 3.2 cm nap; Linzer Products Corp., Flushing, NY) because large chunks of foam were being striped from the covers. The deer stations were placed 10-15 m inside wooded areas, where deer were more secluded and would feed more readily. The feed reservoir of each station was filled with 225 lb (113.5 kg) of whole, shelled corn. To initially attract deer to the stations, extra corn and apple slices were dispersed along trails leading to the stations, at the bases of the stations, and on the stations. The extra bait was discontinued once >1 deer was observed feeding at that station. All other vertebrates eating corn or corn fines (small pieces of corn) were recorded while re-supplying the deer stations.

The insecticide initially used to treat the deer was Synergized Expar Pour-On (active ingredient: 1% permethrin, EPA Registration No. 59-229, Mallinckrodt Vet Inc., Mundelein, IL). Permethrin is a residual insecticide used to kill ectoparasites on domesticated animals. Because this formulation is approved for use on dairy and beef cattle for the control of ectoparasites, the EPA issued a research waiver for use on non-hunted deer at NASA. Fifteen ml of permethrin was applied as evenly as possible via a measured squeeze bottle to each roller, 5 d/wk, for the first month of treatment. After one month, we switched to a higher percentage of permethrin formulation (10% permethrin, Brute^{R}, EPA Reg. No. 89039-7, Y-Tex, Inc. Cody, WY). It was difficult to determine the numbers of deer being treated, so a non-toxic dye, normally used to highlight human eyes, was added to the permethrin (1 gm D&C Green Dye #6 [Tri-Con Colors Inc., Elmwood Park, NJ]/476 ml Brute) to mark the treated deer. Fifteen ml of the permethrin-dye solution were applied to the rollers from mid-November 1995 through December 1998. The rollers generally were treated with the solution 3 times/wk for 8 weeks during 1995, 2.5 times/wk for 9-10 months in 1996-97, and 2 times every other week for 9-10 months in 1998 (Figure 2).

The stations were closed periodically by sliding the trough plates across the feeding troughs and screwing them tightly to the frames. Such closures were effective before and during inclement weather to prevent wetting, molding, and caking of corn fines and clogging of the feeding chute. After inclement weather, permethrin was added to the rollers and the stations were opened for the period scheduled. The stations were also closed when tick stages were inactive during freezing weather in January, February, and part of March; at the end of August and the early part of September when tick activity was low; and during intervals of several days to 1 wk throughout the year to limit permethrin application.

During June 1996, there were about 100 Canadian geese (*Branta canadensis*) at NASA. Several geese started feeding from the stations with the deer, and soon 30 geese were counted feeding from all 4 stations. To prevent the geese intrusion, each feeder was placed on four 15.2 W x 45.7 H x 61.0 L cm concrete blocks. The stations were left on the blocks throughout the study.

Deer counts

Because deer densities influence adult tick densities (Deblinger et al. 1993), deer densities per usable habitat acre (excluding ponds, swamps, buildings, parking lots, etc.) were estimated for both locations. Two types of counting methods were used: direct visual counts

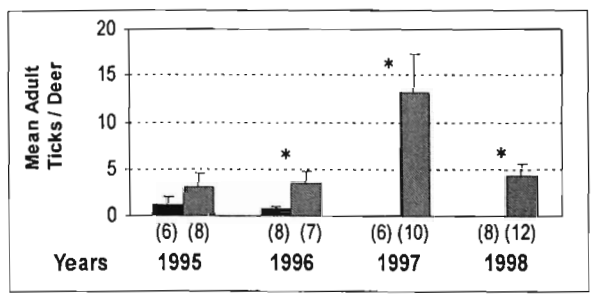

Figure 3. Mean (± SEM) adult *Ixodes scapularis* sampled from deer at NASA and Patuxent. Numbers in parentheses under the bars indicate sampled deer at NASA (solid black bars) and Patuxent (striped bars). Yearly significant differences(*) occurred between locations (1-tailed, 2-sampled T-test) for the following years: 1996 (T=2.01, df=6, P=0.0450); 1997 (T=3.06, df=9, P=0.0068); and 1998 (3.82, df=11, P=0.0014).

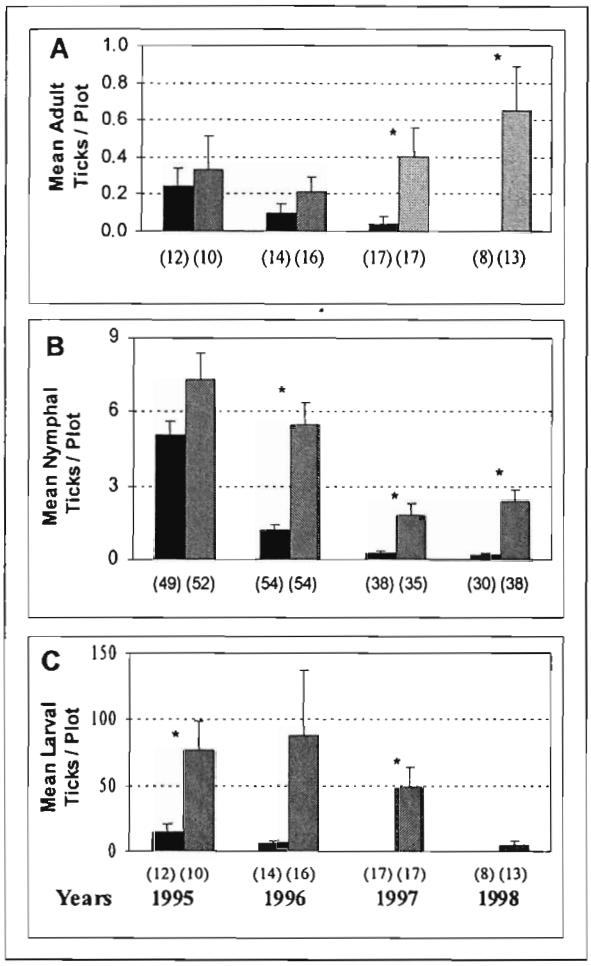

Figure 4. Mean (± SEM) questing *Ixodes scapularis* sampled from test plots. Numbers in parentheses indicate numbers of sampled plots at NASA (solid black bars) and Patuxent (striped bars). The sampling years are shown at the bottom of the graph. An asterisk (*) above the bars indicates a significant difference between locations.

A. Yearly significant differences between adult ticks collected from the two locations occurred for the following years (1-tailed, 2-sampled T-test): 1997 (T=2.13, df=27, P=0.0210); and 1998 (T=2.71, df=22, P=0.0063).

B. Yearly significant differences between nymphal ticks collected from the two locations occurred for the following years (1-tailed, 2-sampled T-test): 1996 (T=4.92, df=59, P<0.0001); 1997 (T=3.43, df=38, p=0.0007); and 1998 (T=4.87, df=49, P<0.0001).

C. Yearly differences between larval ticks collected from the two locations occurred for the following years (2-tailed 2-sampled T-test for 1995, 1-tailed for the other years): 1995 (T=2.53, df=10, P=0.0300); 1996 (T=1.64, df=15, P<0.0600); 1997 (T=3.07, df=16, P=0.0037); and 1998 (T=1.61, df=12, P<0.0660).

conducted by a walking drive-line census at NASA (DeCalesta and Witmer 1990, Penland 1999), and an area strip census involving direct observation from motor vehicles driving a standard route in Patuxent at dusk (Cockrum 1962, Deblinger et al. 1993).

Quantification of insecticide residue on deer

To estimate the number of deer using the deer stations each year, each sampled deer was first evaluated visually for dye on the head, ears, and neck. A 1-2 cm^2 section of hair was cut near the skin from the poll of the head, center of the neck, and upper leg, on 1 side of the deer. In 1996, the sampling area was changed to the junction of the head and neck since that was where the permethrin was mainly deposited (Figure 1). The samples were placed into 20 ml glass scintillation vials and returned to the laboratory to determine the presence of permethrin by high pressure liquid chromatography (HPLC) analysis (Miller et al. 1983). Briefly, 0.4 g of hair was placed in 20 ml acetonitrile in a scintillation vial. The vial was placed on a shaker/roller for 24 h to allow the concentration of permethrin on the hair and solvent to reach equilibrium. A C18 column was used in the Waters HPLC system, along with 80:20 acetonitrile:water mobile phase and a flow rate of 1.5 ml/min with a 254 micron wave length. Known permethrin standards were prepared and 20¼ g of each standard was injected into the HPLC system. Then the samples were injected and compared to the standards of known concentrations. Printouts of the peaks, height of the peaks, and the area under the curve were obtained from the standards and unknown hair samples using a Hewlett-Packard model 3390A computing integrator. A graph of the concentrations of the known standards peak heights versus the peak heights of the unknowns was plotted and compared. Values of the unknowns were read directly from the graphs.

Statistical methods

Three factors associated with *I. scapularis* activity, (1) ticks parasitizing free-ranging deer, (2) questing ticks collected from test plots by dragging, and (3) ticks parasitizing mice trapped from test plots, were measured and each factor was compared between the treated and non-treated locations over 4 y (pre-treatment, 1995; post-treatment, 1996-1998).

The numbers of mice caught per trap-night were compared between locations for each year. The mean densities of ticks infesting each unit (deer, mice, and plots) were compared yearly between locations using the two sample T-test (MINITAB Statistical Software, PWS-KNT, Boston, MA). A significant level (alpha) <0.05 was considered significant.The percentages of ticks

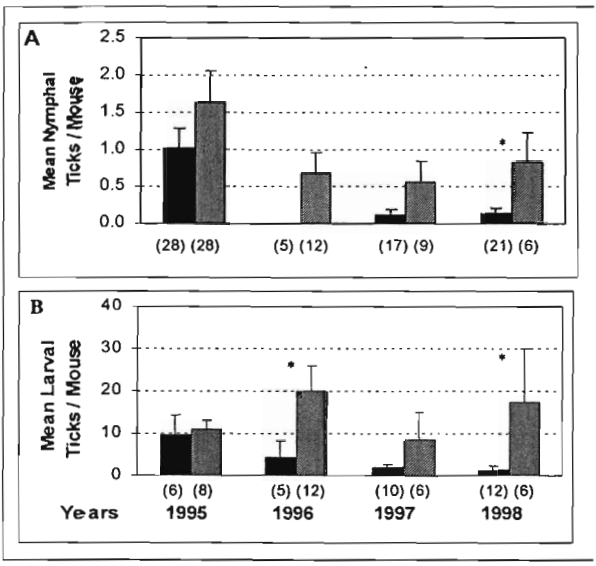

Figure 5. Mean (± SEM) nymphal and larval *Ixodes scapularis* sampled from white-footed mice. Numbers in parentheses show the number of sampled mice at NASA (solid black bars) and Patuxent (striped bars) for each year sampled. The sampling years are shown at the bottom of the graph. An asterisk (*) above the bars indicates a significant difference.
A. Yearly differences for nymphal ticks between locations, 1-tailed 2-sampled T-test: 1996 (T=2.35, df=11, P=0.0390) and 1998 (T=2.74, df=25, P=0.0110).
B. Yearly differences occurred between larval ticks collected from the two locations, 1-tailed 2-sampled T-test: 1996 (T=2.23, df=14, P=0.0430).

infesting each unit were compared yearly between locations using Fisher's Exact Test (Agresti 1992). Permethrin efficacy was determined yearly by comparing ticks captured at Patuxent versus NASA for each unit sampled (Abbott 1925):

$$\text{Yearly Percentage Control} = \frac{\text{mean ticks in non-treated area} - \text{mean ticks in treated area}}{\text{mean ticks in non-treated area}} \times 100$$

The percentages of deer with permethrin on their hair, amount of corn supplied per month, and corn costs were calculated and descriptive statistics are presented in the Figures and Tables.

RESULTS

Pre-treatment tick populations

The mean numbers of adult *I. scapularis* sampled from non-treated deer at both locations were not significantly different from one another (NASA 3.12±1.5 SEM; Patuxent 1.33±0.67; Figure 3), as were the percentages of deer infested with adult ticks (NASA 50% versus Patuxent, 75%; Table 1) between locations. Mean numbers of adult and nymphal *I. scapularis* collected from plots by dragging were not significantly different for either stage between locations (Figure 4).The percentage of plots infested with adult ticks showed no

Table 1. Yearly comparisons between number of deer sampled and percent infested with adult *Ixodes scapularis* from NASA versus Patuxent.

Pre-TRT/ Post-TRT per Y[1]	NASA (Treated Site) T/NT[2]	No. Deer Infested /Sampled	Percentage of Deer Infested (± 95% CI[3])	Patuxent (Control Site) T/NT[2]	No. Deer Infested /Sampled	Percentage of Deer Infested (± 95% CI)	Statistics P Values[4]
Pre-TRT							
1995	NT	3/6	50.0 (11.8-88.2)	NT	6/8	75.0 (34.9-96.8)	0.5804
Post-TRT							
1996	T	4/7	57.1 (18.4-90.1)	NT	7/7	100.0 (59.4-100.0)	0.0962
1997	T	0/10	0.0 (0.0-30.9)	NT	10/10	100.0 (69.2-100.0)	<0.0001
1998	T	0/8	0.0 (0.0-36.9)	NT	11/12	91.7 (61.5-99.8)	<0.0001

[1] Pre-treatment (Pre-TRT) sampling or post-treatment (Post-TRT) sampling per year.
[2] Treatment/Nontreatment (T/NT)- application of permethrin or no application of permethrin to deer.
[3] 95% Exact Confident Interval (CI).
[4] Fisher's Exact Test; two-tailed P-values were calculated for 1995, one-tailed P-values for 1996-1998.

Table 2. Yearly comparison of plots infested with *Ixodes scapularis* sampled at NASA versus Patuxent.

			NASA		Patuxent		Statistics
Tick Stage	Years	T[1]	Plots Infested /Sampled	% Plots Infested (± 95% Exact CI[2])	Plots Infested /Sampled	% Plots Infested (± 95% Exact CI)	P Values[3]
Adult	1995	NT	5/21	23.8 (8.2-47.2)	4/18	22.2 (6.4-47.6)	1.0000
	1996	T	3/31	9.7 (2.1-26.5)	6/28	21.4 (8.4-41.0)	0.1868
	1997	T	1/24	4.2 (0.1-21.1)	10/25	40.0 (21.1-61.3)	0.0028
	1998	T	0/23	0.0 (0.0-14.8)	8/23	34.8 (16.4-57.3)	0.0019
Nymphal	1995	NT	34/52	65.4 (50.9-78.0)	46/49	93.9 (83.1-98.7)	0.0005
	1996	T	33/54	61.1 (46.9-74.1)	44/54	81.5 (68.6-90.8)	0.0163
	1997	T	6/38	15.8 (6.0-31.3)	19/35	54.3 (36.7-71.2)	0.0006
	1998	T	6/38	15.8 (6.0, 31.3)	35/46	76.1 (61.2, 87.4)	<0.0001
Larval	1995	NT	9/14	64.3 (35.1-87.2)	8/12	66.7 (34.9-90.1)	0.6133
	1996	T	10/14	71.4 (41.9-91.6)	9/16	56.3 (29.4-80.3)	0.8931
	1997	T	2/17	11.8 (1.5-36.4)	13/17	76.5 (50.1-93.2)	0.0002
	1998	T	1/11	9.1 (0.2, 41.3)	6/16	37.5 (15.2, 64.6)	0.1121

[1] Treatment (T) occurred at NASA, Oct. 1995-Dec. 1998. No treatment (NT) occurred during sampling of plots Apr.-Oct.1995 at NASA; and Patuxent, Apr. 1995-Dec. 1998.

[2] 95% Exact Confident Interval (CI).

[3] Fisher's Exact Test; two-tailed P-values were calculated for 1995; one-tailed P-values for 1996-1998.

significant difference (Table 2), nor did the percentage of larval infested plots during 1995. The only significant pre-treatment differences between locations were the percentage of plots infested with nymphal ticks (Table 2) and the mean number of larval ticks collected per plot (NASA 13.1±5.2, n = 12; Patuxent 63.6±21.0, n=10; Figure 4).

Only *Peromyscus leucopus* were captured during the study. The mean numbers of nymphs and larvae per mouse pre-treatment were not significantly different between NASA and Patuxent, nor was the percentage of mice infested with nymphal and larval ticks at each location (Figure 5, Table 3). The numbers of mice captured at each location were similar (Table 4). Pre-treatment counts of deer at both locations also were similar (Figure 6).

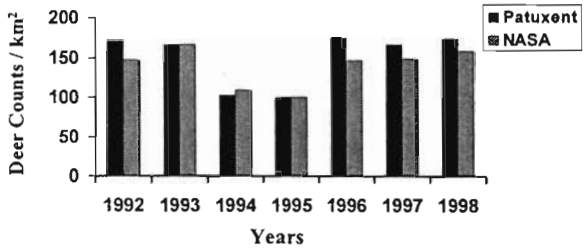

Figure 6. Estimated deer densities at NASA and Patuxent, 1995-1998.

Post-treatment tick populations

Complete elimination of all adult *I. scapularis* parasitizing sampled deer at NASA (only adult autumn tick data are shown) was achieved during the 2nd and 3rd y of deer treatment with permethrin (Figure 3, Table 1), even on those deer sampled without detectible levels of permethrin on their hair. Conversely, deer at Patuxent had significantly higher mean numbers of adult ticks during 1996, 1997, and 1998 (Figure 3). From 1996 to 1998 the percentage of Patuxent deer infested with adults were 100, 100, and 92%, while NASA infestation rates were 57, 0, and 0% (Table 1), respectively.

Overall, mean numbers of questing NASA *I. scapularis* of all stages collected per plot showed a continuing decline to near zero or zero (Figure 4) from 1996 to 1998, and were close to or significantly greater at Patuxent each year (Figure 4). After the second year of treatment, adult ticks sampled from plots at NASA declined to zero (Figure 4). Declining mean nymphal ticks per plot showed significant decreases during 1996 to 1998 (Figure 4). Mean numbers of larvae per plot were significantly different between locations in 1997, and approached the significance level in 1996 and 1998 (Figure 4), with more larvae collected at Patuxent than at NASA during each year post-treatment. Larvae showed extreme clumping at Patuxent (ranges: 1995, 0-263; 1996, 0-800; 1997, 0-200; and 1998, 0-37). Less clumping of larvae was noted at NASA (ranges: 1995, 0-72; 1996, 0-19; 1997, 0-3; and 1998, 0-4). Larval infestations decreased to 9.1% of the plots sampled at NASA in 1998 compared to 37.5% at the control area (Table 2).

Mean numbers of nymphal ticks collected from mice at NASA were significantly less than those collected at Patuxent during 1996 and 1998 (Figure 5). During 1997, mean numbers of nymphal ticks per mouse at NASA were also less than those from Patuxent; however, the differences were not significant (Figure 5). The percentage of mice infested, though lower at NASA than

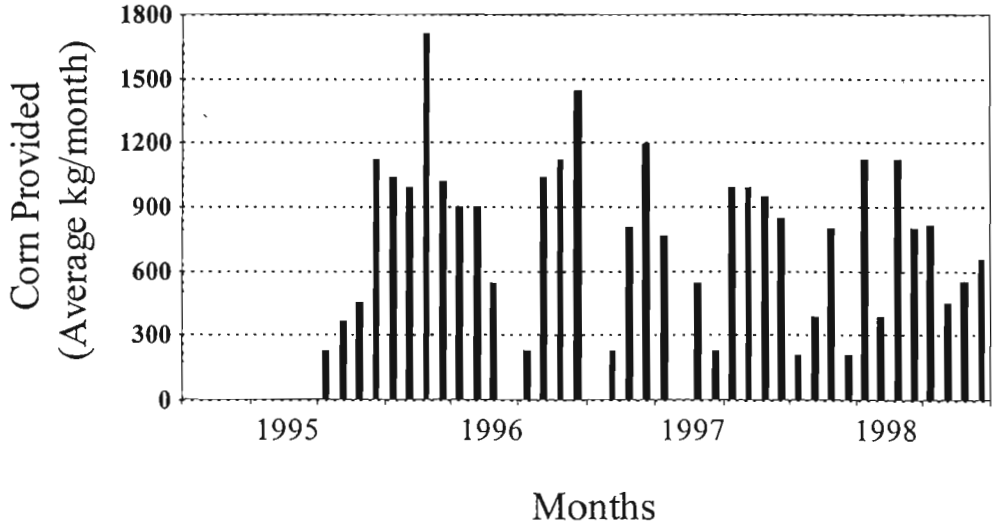

Figure 7. Amount of corn per month provided to deer at NASA, 1995-1998.

Table 3. Yearly comparison of *Peromyscus leucopus* infested with *Ixodes scapularis* collected from NASA versus Patuxent.

			NASA		Patuxent		Statistics[1]
Tick Stage	Years	T[1]	No. Mice Infested /Sampled	Percentage of Mice Infested (± 95% Exact CI[2])	No. Mice Infested/ Sampled	Percentage of Mice Infested (± 95% Exact CI)	P Value[3]
Nymphal	1995	NT	13/28	46.4 (27.5-66.1)	19/28	67.9 (47.7-84.1)	0.1765
	1996	T	0/5	0.0 (0.0-52.2)	5/12	41.7 (15.2-72.3)	0.1280
	1997	T	2/17	11.8 (1.5-36.4)	3/9	33.3 (17.5-70.1)	0.2081
	1998	T	3/21	14.3 (3.1-36.3)	3/6	50.0 (11.8-88.2)	0.1009
Larval	1995	NT	6/6	100 (54.1-100.0)	8/8	100 (63.1-100.0)	1.000
	1996	T	2/5	40.0 (5.3-85.3)	11/12	91.7 (61.5-99.8)	0.0525
	1997	T	8/10	80.0 (44.4-97.8)	4/6	66.7 (22.3-95.7)	0.8819
	1998	T	4/12	33.3 (9.9-65.1)	6/6	100.0 (99.5-100.0)	0.0113

[1] No treatment (NT) occurred during mouse sampling at NASA, 1995, and Patuxent, 1996- 1998. Treatment (T) occurred to deer at NASA during the end of 1995 to 1998.

[2] 95% Confident Intervals (CI).

[3] Fisher's Exact Test; two-tailed P-values were calculated for 1995; one-tailed *P*-values for 1996-1998.

Table 4. Mice caught per trap-night[1] from plots at Patuxent versus NASA.

	NASA		Patuxent		Statistic[2]	
Year	Mice caught per Trap-night	% Positive Traps	Mice caught per Trap-night	% Positive Traps	Z Value	P Value
1995	28/96	29.2	28/104	26.9	0.35	0.724
1996	5/120	4.2	17/124	13.7	-2.66	0.008
1997	17/116	14.7	9/174	5.2	2.57	0.010
1998	21/109	19.3	6/110	5.5	3.17	0.002

[1] Trap-night (number of traps set each night).

[2] Z test

Table 5. Area-wide control of *Ixodes scapularis* measured by three sampling methods.

Units sampled (methods)	Tick stages	% Tick Control[1] 1996	1997	1998
Deer (Deer)	Adults	78	100	100
	Nymphs	100	100	100
Plots (Drag)	Adults	55	90	100
	Nymphs	78	86	91
	Larvae	93	100	92
Plots (Mice)	Nymphs	100	79	70
	Larvae	58	75	95

[1] % Control = $\frac{\text{(Patuxent Mean Ticks - NASA Mean Ticks)}}{\text{(Patuxent Mean Ticks)}} \times 100$, post initiation of permethrin treatment to deer at NASA.

Table 6. Deer hair sampled at NASA for permethrin.

Year	Number Deer Sampled with Perm[1]/Total Deer Sampled	% Deer Sampled with Perm	Deer Count[2]	Estimated Deer Treated With Perm[3]
1995	0/9	0	75	0
1996	3/7	43	69	30
1997	7/1	64	70	45
1998	10/12	83	74	61

[1] Permethrin (Perm) was applied to the first deer station during October, 1995.

[2] Deer counts were conducted yearly, September to December.

[3] Estimated number of deer treated with permethrin = percentage of deer sampled with permethrin-treated hair times deer counts for each y.

Table 7. Calculations related to the quantities of permethrin applied using 4-poster deer stations at NASA, and comparison of area-wide spray to 4-poster tick control.

	1996	1998
A. Maximum Estimated Permethrin Applied to Deer		
1. Number of applications/wk	2.5	1
2. Total quantity of Brute applied/application (ml)[1]	160	160
3. Estimated quantity of Brute applied by all deer/wk assuming a 90% transfer rate (ml)[2]	360	144
4. Estimated number of deer that applied Brute[3]	30	61
5. Quantity of Brute/deer/wk	12	2.4
6. Estimated permethrin active ingredient (AI) applied (g/deer/wk)[4]	1.03	0.21
7. Estimated permethrin AI/kg body weight (mg/kg/wk)[5]	20.6	4.12
B. Maximum Estimated Permethrin Applied to NASA		
1. Total Quantity of Brute dispensed/wk (ml)	400	160
2. Total quantity of Brute dispensed over 46 wks of treatment	18,400	7,360
3. Total permethrin (AI) dispensed over 46 wks (g)	15,824	6,329
4. Annual total permethrin AI/hectare (g/ha)	13.07	5.23
C. Comparison of Area-wide Spray Control vs 4-Poster Tick Control		
1. Typical area-wide spray control using cyfluthrin applied twice/yr (g AI/ha)	410 820	820
2. Comparison ratio of total pesticides (AI) used/yr: area-wide spray to 4-poster tick control	63	157

[1] Forty ml applied to each of 4 deer stations.
[2] Remaining 10% applied by other animals.
[3] See Table 6.
[4] Brute is 10% permethrin with a 0.86 specific gravity.
[5] Estimated average deer weight: 50 kg.
[6] Estimated 121 hectares used by deer.
[7] Solberg et al. 1992, Stafford 1997.

Table 8. Estimated yearly corn and permethrin supplied to deer feeders and costs, and estimated labor costs to maintain the deer feeders.

Year	Corn Supplied/Yr Lbs (kg)	Corn Cost $/Yr[1]	Permethrin Cost/Yr[2] $	Labor Cost/Yr $
1995	4,730 (2,150)	433	103	6,528
1996	23,125 (10,511)	2,070	489	15,300
1997	16,825 (7,647)	1,506	356	10,880
1998	16,300 (7,409)	1,459	345	8,160

[1]Based on an average corn cost of $8.95/100 lbs.
[2] Based on market value of Brute.

at Patuxent, was not significantly different, even though no ticks were found on mice at NASA in 1996 and only a few in 1997-1998 (Table 3). The percentage control of nymphs parasitizing mice at NASA from 1996 to 1998 was 100, 79, and 70% (Table 5).

During 1996, mean numbers of larval ticks collected per mouse at NASA were significantly less than those collected at Patuxent (Figure 5). Declining larval populations continued at NASA in 1997 and 1998 but were not significantly different between locations (Figure 5). Nevertheless, by 1998, the percentage of larval ticks infesting mice was significantly less at NASA compared to Patuxent (Table 3).

Deer densities and sampling

Deer were counted each autumn at both locations. In 1995, walking drive-line deer censuses determined a range of 50-75 deer (n=5) for a total of 630 acres (2.55 km^2) at NASA (Penland 1999), or a total of 300 deer-usable acres (1.21 km^2). The maximum number of counted deer at NASA (75) occurred in 1995. NASA and Patuxent had similar deer densities, 100 deer/deer usable 2.6 km^2, during 1995 (Figure 6). From 1996-1998, the deer densities at both locations increased, with slightly more deer sighted at Patuxent compared to NASA.

The NASA location was not as secure for deer as expected. Two to 5 deer per y were observed walking out gates, jumping fences, going through holes in the fence, or standing outside the areas. Generally most deer that left returned, though several remained outside or went elsewhere. Two marked deer were killed by cars outside the fenced perimeter during the study. Deer emigrated from Patuxent also. One ear-tagged Patuxent buck was shot 11 miles north of Patuxent and another was sited 11 miles southwest of Patuxent. However, no Patuxent deer were ever sited at NASA or vice versa.

During the autumns of 1995-1998, a total of 31 deer were sampled at NASA, 13 male and 16 female deer, while a total of 37 deer were sampled at Patuxent, 8 males and 28 females. The sexes and ages of 3 deer were not recorded. More male deer were sampled at NASA as compared with Patuxent, both in total number and percentages of deer sampled. The numbers and estimated ages of deer captured and recorded were: NASA, 0.5-1.8 y, 13 deer; 2-3.8 y, 11 deer; and ≥4 y, 5 deer; Patuxent, 0.5-1.8 y, 15 deer; 2-3.8 y, 12 deer; and ≥ 4 y, 4 deer.

Mice captured

The numbers of *P. leucopus* captured yearly varied significantly between locations from 1996-1998 (Table 4). However, overall number of mice captured/y ranged from 28 to 5 mice at NASA and 28 to 6 mice at Patuxent over the 4 y of trapping.

'4-Poster' usage

Deer stations were efficacious in attracting, feeding, and permethrin-treating free-ranging deer (Table 7). Deer that were sampled the greatest distance from all 4-poster deer stations had permethrin on their hair, indicating they had traveled ≥1000 m to use a station. Some ear-tagged deer were observed using 1 station at least twice a day and some were observed eating at different stations during the same week. As many as 4 deer fed per station.

While supplying corn and permethrin to the deer stations, other animals were observed eating corn from the stations, including Canadian geese, *B. canadensis;* gray squirrels, *Sciurus carolinensis*; gray foxes, *Urocyan cinereoargenteus;* racoons, *Procyon lotor*; white-footed mice; eastern chipmunks, *Tamias striatus*; American crows, *Corvus brachyrhynchos;* and small unidentified passerine birds.

Chunks of foam roller covers were found missing from the rollers from 1995 to 1996, presumably stripped by small to medium mammals since no foam pieces were

found. It appeared the foam was either used as nesting material or eaten. This necessitated replacement of the covers as often as every several days to several weeks until the type of covers was switched to Synthetic Lambskin in 1997, thus eliminating the problem. Even though the purchased corn was re-cleaned by the provider, cornmeal and corn fines were still present. This necessitated cleaning the deer station chutes and troughs after rains, or the deer would not feed and self-apply permethrin due to caking and molding of the corn meal. Eventually we changed corn suppliers and eliminated the problem.

Detection of permethrin on deer hair

In mid-October 1995, soon after the permethrin-dye solution was added to the first station, several small groups of deer were observed eating corn or foraging along the roadside with "blue-green" dye on their ears, indicating self-treatment with the permethrin-dye solution. Nevertheless, none of the deer sampled had visible dye on their head, neck, or ears, nor permethrin on their hair samples in 1995 (Table 6). NASA deer with detectable permethrin levels increased steadily from 1996 (43%) to a minimum of 83% in 1998 (Table 6). No ticks were found on the permethrin-treated deer. During HPLC analysis, the dye eluded first and did not interfere with the permethrin cis- and trans-isomer peaks. Samples as low as 0.6 µg permethrin/gm hair could be detected.

Estimated permethrin applied to deer

Based on yearly deer counts and the amount of permethrin added to the stations, a maximum estimate of 20.6 mg permethrin/kg deer/wk was applied during permethrin treatment in 1996 (Table 7). By 1998, the amount had been reduced to 4.12 mg permethrin/kg deer/wk (Table 7). The yearly cost based on market value over the last treatment year was approximately $345 for all 4 stations to treat 61-74 deer (Tables 6 and 8).

Corn and permethrin use and costs

Corn supplied to the stations increased from 245 kg in September to a high of 1724 kg in March 1996 (Figure 7). Corn was thereafter limited to deer by closing the feeders for 1 to 2 d per wk to a month during selected times. Yearly amounts and costs of corn and permethrin supplied to the stations and estimated labor costs to maintain the stations are shown in Table 8.

DISCUSSION

Control of ticks

The insecticide Permethrin was used to control ticks. One application of permethrin on cattle will control horn, face, stable, horse, house, black, and deer flies, lice,and mosquitoes for approximately 2 wk when applied according to directions (Y-Tex label, Cody, WY). Permethrin has also been reported to have a repellent effect against some tick species (Lane and Anderson 1984). Permethrin self-treatment by deer drastically reduced all active stages of the tick population, both on and off deer, throughout the 3-y treatment at NASA (Figures 3-5, Tables 1-3, and 5).

Pre-treatment sampling

I. scapularis populations were well established at NASA before 1992 (Penland 1999) and at Patuxent before 1989 (Amerasinghe et al. 1992, Daniels et al. 1993, Schmidtmann et al. 1998). Overall, pre-treatment sampling at both locations was not significantly different in tick populations of all active stages per unit sampled, with the exceptions of percentage of plots infested with nymphal ticks (Table 2) and mean numbers of larvae/plot (Figure 4C). However, there were no pre-treatment differences in mean nymphal densities/plot (Figure 4B) and percentage of plots infested with larvae (Table 2). These differences may have been caused by chance occurrence of sampling plots with higher spatial aggregations (clumping) at Patuxent and a low number of plots sampled for larvae at both locations. Spatial aggregation of larvae, nymphs, and adults is a well-known characteristic of *I. scapularis* (Ginsberg and Ewing 1989, Daniels and Fish 1990, Stafford 1992, Telford et al. 1992, Ostfeld et al. 1996a, b). A replete female tick lays 860-3,000 eggs (Hooker et al. 1912, Rogers 1953, Oliver et al. 1993) near the location where she dropped from the host, and with larvae only traveling 1-2 m from the egg mass, larvae are the highest clumped of all motile stages (Daniels and Fish 1990, Ostfeld et al. 1996a). In 1995, the largest larval clumps were found at Patuxent (range 0-263 larvae per plot), while the range at NASA was 0-30 larvae/plot.

Post-treatment tick populations

Deer are major hosts for adult *I. scapularis* and also an important blood meal source for immature stages (Wilson et al. 1990). Maximum numbers of 1,000-2,000 larvae and >40-60 nymphs per deer have been reported (Piesman and Spielman 1979, Anderson and Magnarelli 1980, Telford et al. 1988). We found >60 larvae and 21 nymphs parasitizing a deer's head, neck, and chest at Patuxent in June 1996, but not from deer sampled in June at NASA (data not presented).

The clear decreases in immature stages sampled from plots and mice during 1996 (Figures 4-5) also indicate that the permethrin-treated deer killed nymphal

and larval ticks as well as adult ticks during 1996. If permethrin only killed adult ticks in 1996, a decrease in larval ticks would not be observed until 1997, and nymphal ticks would not decrease until 1998. An early knockdown of immature ticks is important to prevent further transmission of *B. burgdorferi* by nymphal ticks. In addition, though deer are generally considered as systemically incompetent reservoirs of *B. burgdorferi* (Telford et al. 1988), *B. burgdorferi* spirochetes have been transferred experimentally from artificially infected deer to non-infected immature ticks at least 43 d after infection (Oliver et al. 1992), and viable spirochetes have been isolated from an ear injection site of a deer at least 70 d post-infection (Luttrell et al. 1994). The route of transmission may be non-systemic since *B. burgdorferi* transmission between co-feeding ticks of different stages occurs in non-systemically infected rodents (Patrican 1997). Thus it may also be important to kill all stages of ticks parasitizing deer to prevent non-systemic transmission of *B. burgdorferi*.

Though larval sampling showed decreased mean numbers per plot at NASA compared to Patuxent through 1998, the pre-treatment significant difference observed between locations in 1995 obscured the meaning of the significant difference found in 1997 (Figure 4). Additional larval sampling through the end of July may have provided more data and given a more accurate picture over the 4 y of sampling.

The sharp decrease and continued suppression in the tick population at NASA (Figures 3-5, Tables 1-3 and 5) could only be caused by permethrin treatment of deer, even though the study was a single replication and lacked treatment randomization of the two areas. Lack of randomization was minimized due to similarities in pre-treatment tick sampling at both locations, strong post-treatment effects demonstrated on the units sampled at NASA, and consistency of the treatment effects at NASA over the 3 treatment years. In addition, two additional non-treated control areas, 30 to 500 m outside the NASA security fence, were sampled for nymphal ticks by dragging in 1998 and confirmed significantly higher nymphal populations per plot compared with the NASA population (data not presented). Furthermore, the mean number of nymphal ticks sampled per plot at the new control areas were virtually identical to those at Patuxent in 1998, demonstrating that only the NASA tick population decreased to near zero. At no time did the mean number of adult ticks collected from deer at Patuxent or Ft. Meade, MD in 1999, another area adjoining Patuxent, decrease to or approach zero (J.F. Carroll, unpublished data), as happened at NASA.

Deer densities

Deer densities may affect tick densities[1]. Several years of deer census baseline data at NASA were recorded by the walking drive-line census (Penland 1999), one of the most accurate methods of counting deer within fenced enclosures (DeCalesta and Witmer 1990). A strip census, recommended for larger areas not completely enclosed (Cockrum 1962), was used at Patuxent. Even though these methods were different, it was decided to use the most accurate method for each location.

Deer counts in 1995 indicated that pre-treatment deer densities were similar at both locations. Though deer counts varied from year to year and between locations, the overall population trends between the small deer herds remained roughly similar or slightly higher at Patuxent (Figure 6). The harsh winters of 1993 and 1994 decreased deer densities at both locations in 1994 and 1995, with many winter kills found in the spring months at Patuxent (H. Obrecht, Patuxent Wildlife Research Center, Laurel, MD, personal communication). Small groups (5-10 deer/group) of juvenile and adult deer of both sexes were observed crossing the Patuxent River daily from the Patuxent North Tract into the Central Tract control site to feed and then returning to the North Tract. No daily deer migration was observed at NASA. However, yearly migration of deer was observed at both locations, with greater numbers of deer migrating to and from Patuxent than at NASA. The few deer (1-5/y) that left NASA consisted of either sex and all ages >6 mo. Though the deer counts at Patuxent appeared to be slightly higher than at NASA during the last 3 y, the counts at Patuxent may have reflected more immigration or a less accurate counting method.

Mice

Counting *I. scapularis* on hosts is the most efficient method of monitoring tick populations when tick densities are low (Lane et al. 1991). Thus, anticipating that our control method would yield low numbers of immature ticks in the treated area toward the end of the study, we included mice as one of our sampling methods. Yearly fluctuations in mouse densities at a given location are the norm, varying as much as tenfold between years at the same trapping sites, caused by such extrinsic factors as climate, mast production, and predation (Ostfeld et al. 1996c). We expected yearly mouse densities at NASA and Patuxent would be somewhat comparable to one

[1]Ginsberg, H.S. 1992. Ecology and management of ticks and Lyme disease at Fire Island National Seashore and selected national parks. Scientific monograph NPS/NRSUNJ/NRSM-92/20, U.S. Department of the Interior, National Park Service.

another, though mouse densities per se were not measured, only mice captured per trap-night. During pre-treatment comparison of mice captured per trap-night, no significant difference was observed (Table 4). However, we observed significant differences in 1996-1998 (fewer captures at NASA in 1996 but more in 1997 and 1998 compared to captures at Patuxent), perhaps caused by the small capture numbers, predation, or differences in mast production. There was also evidence of trap invasion and tampering, such as sprung traps most likely caused by squirrels, raccoons, opossums, and deer. Several traps were also located in nearby creeks, indicating raccoon displacement. Thereafter, we tied the traps to small saplings or bushes.

Efficacy of deer feeders and acaricide application

The deer stations were initially baited with corn in the feeders. Pieces of apple and corn were also spread on the stations or nearby on the trails to help attract deer. Once one deer started to feed, other deer were attracted to the stations and also started to feed, at which time the extra bait was discontinued. Our first deer treatment year (1996) resembled the preliminary study reported by Pound et al. (2000) using the acaricide amitraz to self-treat 9 deer in a small-fenced pasture. He reported 92% and 97% control of adult and nymphal *A. americanum*. Our permethrin efficacy was 78 and 100% for nymphal and adult *I. scapularis*, and this increased to 100% for all stages in the second year of treatment and remained there for the third year of treatment (data for immature ticks are not presented).

Deer self-application of the permethrin-dye solution demonstrated that ca. 0.2 gm A.I. of permethrin was applied directly to the head, ears, and neck per deer per week by the last year of treatment (Table 7). Pound et al. (2000) also reported that dye applied to the rollers and transferred to the deer was spread from their heads to their rear sides and axillae during self-grooming, thus reaching most of the parasitizing ticks. Since > 90% of *A. americanum* adults are found on the head, ears, neck, and chest region of white-tailed deer[2], and ca. 87% of *I. scapularis* adults are also found on these areas (Schmidtmann et al. 1998), we expected that area-wide control would occur if the same percentage of *I. scapularis* adults were killed while feeding and mating on deer over a 3 y treatment period. However, killing all active stages of ticks on deer would theoretically shorten this lag time. Therefore, we applied permethrin during the activity periods of each free-living stage and achieved 100% knockdown of all tick stages parasitizing sampled deer by the 2nd year of treatment. In addition, we observed large reductions in all questing ticks and ticks parasitizing mice. In contrast, in a study on Great Island, Cape Cod, MA, where 51 of 52 deer were sacrificed to control ticks, Wilson et al. (1988) showed a slower decline in larval (mean: ~1 tick/mouse) and nymphal (mean: ~0.6 ticks/mouse) ticks parasitizing mice, while sampled adult questing ticks even increased 3 y after removal of deer. Because deer are good hosts for immature ticks (Piesman and Spielman 1979, Main et al. 1981, Telford et al. 1988), the difference between the Wilson study (1988) and our study presumably was caused by the permethrin-treated deer killing all stages of active ticks.

The first group of 5-10 deer feeding at stations newly supplied with permethrin-dye solution applied more permethrin than later deer due to less permethrin-dye being on the rollers, as shown by darker blue-colored ears. To maximize effectiveness of treatment, we initially supplied the solution to the rollers for ~5 d per week during the first month, depending on the weather. During the next 2 d, the feeder troughs were closed. Deer learned rapidly that no feed was present when the plates were closed. However, if open but empty, the deer pawed the troughs, knocking the feeders around and even off the concrete blocks. During 1997, permethrin was applied 2 times/week, while in 1998 permethrin was applied only twice a week for the 1st week of a 2-week period (Table 7).

All deer sampled after the stations were in operation in 1995 were darted at a distance at least 175 m from the stations. All of these deer had permethrin-free hair samples and dye-free ears, heads, and necks. From 1996 to 1998, a range of 0-9.6 µg permethrin/g hair was detected from the hair samples. The percentages of deer with permethrin were probably higher than shown, since we only took 2 or 3 small samples from the head-neck interface and the ears on one side of the deer. Few bucks appeared to use the stations during the breeding season (rut), but were observed using the stations continuously during spring, summer, and early autumn. A small amount of permethrin on the deer may have been reduced by rubbing against underbrush and trees. Rubbing may contribute to permethrin distribution over other parts of the deer, to ticks questing on underbrush and tree trunks (Carroll 2002), and to other animals using the same trails. Permethrin treatment of other animals, including self-treatment at the stations while eating corn and removal of the treated foam from the rollers, may also contribute to area-wide control of ticks, especially in areas not

[2]George, E.J., J.M. Pound, J.A. Miller, D. Fish, G.A. Mound, K. Stafford III, J.F. Carroll, T.L. Schulze, T.J. Daniels, and T.N. Mather. 1997. USDA northeast area-wide tick control project. USDA-ARS, Kerrville, TX.

frequented by deer (i.e., racoon, squirrel, fox, and mice nests).

A comparison can be made of the relative amounts of active ingredient (AI) of pesticide used in controlling ticks with the "4-poster" tick control system of self-treatment of deer and the area-wide spray treatments on shrubs, leaf litter, and grass currently recommended. Based on the number of squirrels and other mammals observed eating corn from the deer stations during the daytime, we conservatively estimated that 10% of the permethrin was used by these small mammals and only 90% was applied by the deer (Table 7). In 1996, 20.6 mg permethrin (AI)/kg deer/week were applied using the "4-poster," and that treatment was reduced in 1998 to a maintenance dose of 4.12 mg permethrin (AI)/kg deer/wk. Based on the 121 hectare area (deer usable area), an estimated 13 gm permethrin (AI)/hectare (ha) were applied in 1996 and 5.2 gm/ha were applied in 1998 (Table 7). By comparison, area-wide spray treatment with cyfluthrin, a commonly used pesticide for controlling *I. scapularis*, was applied at the rate of 410 gm cyfluthrin (AI)/ha (Solberg et al. 1992), and recommended twice a year (Stafford 1997), giving a total of 820 gm cyfluthrin (AI)/y. Therefore, the self-treatment of deer provided 63 fold annual reduction in pesticide application to the environment in 1996 and a 157-fold annual reduction in 1998 compared to a typical area-wide spray treatment. In addition, the use of the "4-poster" control system confined the pesticide to either the device or the deer and therefore should be more environmentally friendly than area-wide spraying.

Acaricide treatment of deer at NASA should be continued to eliminate any surviving residential and immigrating ticks. In addition, new studies are needed to determine if: 1) continued or reduced permethrin application can continue to give the same or better area-wide control of *I. scapularis* populations, 2) the acaricide should be switched at some point to prevent development of permethrin resistance in ticks, and 3) other mammals should be treated at different types of bait stations with more appropriate bait to expedite and facilitate elimination of all stages of ticks.

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REFERENCES CITED

Abbott, W.S. 1925. A method for computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

Agresti, A. 1992. A survey of exact inference for contingency tables. Statist. Sci. 7: 131-153.

Amerasinghe, F.P., N.L. Breisch, A.F. Azad, W.F. Gimpel, M. Greco, K. Neidhardt, B. Pagac, J. Piesman, J. Sandt, T.W. Scott, and K. Sweeney. 1992. Distribution, density, and Lyme disease spirochete infection in *Ixodes dammini* (Acari: Ixodidae) on white-tailed deer in Maryland. J. Med. Entomol. 29: 54-61.

Anderson J.F. and L.A. Magnarelli. 1980. Vertebrate host relationships and distribution of ixodid ticks (Acari: Ixodidae) in Connecticut, USA. J. Med. Entomol. 17: 314-323.

Battaly, G.R. and D. Fish. 1993. Relative importance of bird species as hosts for immature *Ixodes dammini* (Acari: Ixodidae) in a suburban residential landscape of southern New York State. J. Med. Entomol. 30: 740-747.

Carroll, J.F. 2002. A survey for nymphs of host-seeking *Ixodes scapularis* and *Amblyomma americanum* (Acari: Ixodidae) on tree trunks in deciduous forests. J. Med. Entomol. 39: 237-240.

Centers for Disease Control and Prevention. 2001. Lyme disease-United States, 1999. Morbid. Mortal. Weekly Rpt. 50: 181-185.

Cockrum, E.L. 1962. *Introduction to Mammalogy*. 139 pp. The Ronald Press Co., New York.

Daniels, T.W. and D. Fish. 1990. Spatial distribution and dispersal of unfed larval *Ixodes dammini* (Acari: Ixodidae) in Southern New York. J. Med. Entomol. 19: 1029-1033.

Daniels, T.W., D. Fish, and I. Schwartz. 1993. Reduction of nymphal *Ixodes scapularis* (Acari: Ixodidae) and Lyme disease risk by deer exclusion. J. Med.

Entomol. 30: 1043-1049.

Deblinger, R.D., M.L. Wilson, D.W. Rimmer, and A. Spielman. 1993. Reduced abundance of immature *Ixodes dammini* (Acari: Ixodidae) following incremental removal of deer. J. Med. Entomol. 30: 144-150.

DeCalesta, D.S. and G.W. Witmer. 1990. Drive-line census for deer within fenced enclosures. Res. Pap. NE-643. Radnor, PA: United States Department of Agriculture, Forest Service, Northeastern Forest Experimental Station, pp. 1-4.

Duncan, I.M. and N. Monks. 1992. Tick control on Eland (*Taurotragus oryx*) and Buffalo (*Syncerus caffer*) with flumethrin 1% pour-on through a Duncan Applicator. J. Sth. Afr. Vet. Assoc. 63: 7-10.

Falco R.C.and D. Fish. 1988. Prevalence of *Ixodes dammini* near the homes of Lyme disease patients in Westchester County, New York. Am. J. Epidemiol. 127: 826-830.

Giles Jr., R.H. 1978. *Wildlife management techniques.* 3rd ed. pp. 380-401. Wildl. Soc., Washington, D.C.

Ginsberg, H.S. and C.P. Ewing. 1989. Habitat distribution of *Ixodes dammini* (Acari: Ixodidae) and Lyme disease spirochetes on Fire Island, New York. J. Med. Entomol. 26: 183-189.

Hooker, W.A., F.C. Bishopp, and H.P. Wood. 1912. The life history and bionomics of some North American ticks. U.S. Dept. Agric. Bur. Entomol. Bull. 106: 1-239.

Keirans, J.E. and T.R. Litwak. 1989. Pictorial key to the adults of hard ticks, Family Ixodidae (Ixodida: Ixodoidea), east of the Mississippi River. J. Med. Entomol. 26: 435-448.

Lane, R.S. and J.R. Anderson. 1984. Efficacy of permethrin as a repellent and toxicant for personal protection against the Pacific Coast tick and the Pajaroello tick (Acari: Ixodidae and Argasidae). J. Med. Entomol. 21: 692-702.

Lane, R.S., J. Piesman, and W. Burgdorfer. 1991. Lyme borreliosis: Relation of its causative agent to its vectors and hosts in North America and Europe. Annu. Rev. Entomol. 36: 587-609.

Luttrell, M.P., K. Nakagaki, E.W. Howerth, D.E. Stallknecht, and K. A. Lee. 1994. Experimental infection of *Borrelia burgdorferi* in white-tailed deer. J. Wildl. Dis. 30: 146-154.

Main, A.J., H.E. Sprance, K.O. Kloter, and S.E. Brown. 1981. *Ixodes dammini* (Acari: Ixodidae) on white-tailed deer (*Odocoileus virginianus)* in Connecticut, USA. J. Med. Entomol. 18: 487-496.

Miller, J.A., D.D. Oehler, and S.E. Kunz. 1983. Release of pyrethroids from insecticidal ear tags. J. Econ. Entomol. 76: 1335-1340.

Oliver, J. H. Jr, D. Stallknecht, F.W. Chandler, A.M. James, B.S. McGuire, and E. Howerth. 1992. Detection of *Borrelia burgdorferi* in laboratory-reared *Ixodes dammini* (Acari: Ixodidae) fed on experimentally inoculated white-tailed deer. J. Med. Entomol. 29: 980-984.

Oliver, J.H., Jr., D. Stallknecht, F.W. Chandler, A.M. James, C. Chen, W.S. Irby, E.M. Dotson, and D.K. McLain. 1993. Conspecificity of the ticks *Ixodes scapularis* and *Ixodes dammini* (Acari: Ixodidae). J. Med. Entomol. 30: 54-63.

Ostfeld, R.S., K.R. Hazler, and O.M. Cepeda. 1996a. Temporal and spatial dynamics of *Ixodes scapularis* (Acari: Ixodidae) in a rural landscape. J. Med. Entomol. 33: 90-95.

Ostfeld, R.S., M.C. Miller, and K.R. Hazler. 1996b. Causes and consequences of tick (*Ixodes scapularis*) burdens on white-footed mice (*Peromyscus leucopus).* J. Mammal. 77: 266-273.

Ostfeld, R.S., C.G. Jones, and J.O. Wolff. 1996c. Of mice and mast. Ecological connections in eastern deciduous forests. BioScience. 46: 323-330.

Patrican, L.S. 1997. Acquisition of Lyme disease spirochetes by cofeeding *Ixodes scapularis* ticks. Am. J. Trop. Med. Hyg. 57: 589-593.

Penland, K.I. 1999. Forest composition and tree seedling success in deer browsed forest patches at the Goddard Space Flight Center. M.S. dissertation, University of Maryland, College Park, Maryland. pp. 13-17.

Piesman, J. and A. Spielman. 1979. Host-association and season abundance of immature *Ixodes dammini* in southeastern Massachusetts. Ann. Entomol. Soc. Am. 2: 929-932.

Pound, J.M., J.A. Miller, and C.A. Lemeilleur. 1994. Device and method for its use as an aid in control of ticks and other ectoparasites on wildlife. U.S. Patent #5,367,983 dated 29 November 1994 assigned to The United States of America as represented by the Secretary of Agriculture, Washington, DC.

Pound, J.M., J.A. Miller, J.E. George, and C.A. Lemeilleur. 2000. The '4-Poster' passive topical treatment device to apply acaricide for controlling ticks (Acari: Ixodidae) feeding on white-tailed deer. J. Med. Entomol. 37: 588-594.

Rogers, A.J. 1953. A study of the Ixodid ticks of northern Florida, including the biology and life history of *Ixodes scapularis* Say (Acari: Ixodidae). Ph.D. dissertation, University of Maryland, College Park.

Schmidtmann, E.T., J.F. Carroll, and D.W. Watson. 1998. Attachment-site patterns of adult blacklegged ticks (Acari: Ixodidae) on white-tailed deer and horses.

J. Med. Entomol. 35: 59-63.

Schluze, T.L., M.F. Lakat, B.S. Bowen, W.E. Parkin, and J.D. Shisler. 1984. *Ixodes dammini* (Acari: Ixodidae) and other Ixodid ticks collected from white-tailed deer in New Jersey, USA. I. Geographical distribution and its relation to selected environmental and physical factors. J. Med. Entomol. 21: 741-749.

Solberg, V.B., K. Neidhardt, M.R. Sardelis, F.J. Hoffmann, R. Stevenson, L.R. Boobar, and H.J. Harlan. 1992. Field evaluation of two formulations of cyfluthrin for control of *Ixodes dammini* and *Amblyomma americanum* (Acari: Ixodidae). J. Med. Entomol. 29: 634-638.

Sonenshine, D. 1991. *Biology of Ticks*. Oxford Univ. Press, New York, New York.

Sonenshine, D., S.A. Allen, R.A. Noval, and M.J. Burridge. 1996. A self-medicating applicator for control of ticks on deer. Med. Vet. Entomol. 10: 149-154.

Stafford III, K.C. 1992. Oviposition and larval dispersal of *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 29: 129-132.

Stafford III, K.C. 1993. Reduced abundance of *Ixodes scapularis* (Acari: Ixodidae) with exclusion of deer by electric fencing. J. Med. Entomol. 30: 989-996.

Stafford III, K.C. 1997. Pesticide use by licensed applicators for the control of *Ixodes scapularis* (Acari: Ixodidae) in Connecticut. J. Med. Entomol. 35: 552-558.

Telford III, S.R., T.M. Mather, S.I. Moore, M.L. Wilson, and A. Spielman. 1988. Incompetence of deer as reservoirs of the Lyme disease spirochete. Am. J. Trop. Med. Hyg. 39: 105-109.

Telford III, S.R., S.S. Urioste, and A. Spielman. 1992. Clustering of host-seeking nymphal deer ticks (*Ixodes dammini*) infected by Lyme disease spirochetes (*Borrelia burgdorferi*). Am. J. Trop. Med. Hyg. 47: 55-60.

Whitaker Jr, J.O. 1980. *The Audubon Society field guide to North American mammals*. Alfred A. Knopf, New York.

Wilson, M.L., S.R. Telford III, J. Piesman, and A. Spielman. 1988. Reduced abundancy of immature *Ixodes dammini* (Acari: Ixodidae) following removal of deer. J. Med. Entomol. 25: 224-228.

Wilson, M.L., T.S. Litwin, T.A. Gavin, M.C. Capkanis, D.C. Maclean, and A. Spielman. 1990. Host dependent differences in feeding and reproduction of *Ixodes dammini* (Acari: Ixodidae). J. Med. Entomol. 27: 945-954.